ТЕХНІЧНІ НАУКИ

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MEASUREMENT OF DIELECTRIC PERMEABILITY OF BIOLOGICAL SUBSTANCES

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For measurement of electrophysical parameters of substances the greatest distribution was gained by resonant methods owing to high precision of the received results. The main idea of all resonant methods consists in observation of resonant curves of an oscillatory contour in which the sample of the studied substance is placed. The carried-out analysis of works has shown that the accuracy of measurements of dielectric permeability depends on stability of frequency of the generator and good quality of the measuring resonator. The equipment intended for measurement of changes of dielectric parameters of liquid has to provide not only the necessary level of the brought power and frequency of a signal, but also to meet high requirements for stability of frequency, extent of suppression of discrete components in a range of an output signal, to dimensions, reliability, profitability and service life.

Key words*: dielectric permeability, resonator, fluctuations, frequency, excitement, wave guide, measurements.*

Introduction. The work analysis showed that the accuracy of dielectric constant measurements depends on the generator frequency stability and the quality factor of the measuring resonator. Equipment designed to measure changes in dielectric parameters of a liquid should not only provide the necessary level of input power and signal frequency, but also meet high requirements for frequency stability, degree of suppression of discrete components in the output signal spectrum, dimensions, reliability, efficiency and service life. The results of numerical analysis show that for informational impact on the biological effect, radiation sources are needed in the range of 70-75 GHz with instability, phase noise level of 120-130 dB / Hz at the frequency of the offset from the carrier frequency of 10 kHz and attenuation of discrete components in the output signal spectrum at 40 -50dB

The absence of sources of fluctuations in the EHF range that satisfy the above requirements has put forward the need to create such a source.

In the millimeter wavelength range, an open resonator (OR) is a highly sensitive instrument for measuring the electrophysical characteristics of substances. When conducting research, flat samples are used, as a rule, and the main oscillation TEM_{00q} is excited in the resonator. Thanks to the use of the hemispherical geometry of the resonator, errors associated with determining the angular position of the sample are eliminated, since the latter in this case is placed on a flat mirror RR. In a number of practical cases, it is necessary to investigate samples having a cylindrical shape. In this case, there is a technical difficulty associated with the location of such a sample in the volume of the resonator, since for each measurement, the latter must be placed in an area with the same electric field strength.

Research results. To determine the reliability of the parameters of an open hemispherical resonator, it was decided to conduct experimental studies. The block diagram of the experimental setup, with the help of which studies were conducted to determine the effectiveness of the excitation of TEM_{01q} oscillations in hemispherical OR TEM_{01q} in a resonator with a segment of an oversize circular waveguide, is shown in Fig. 1.

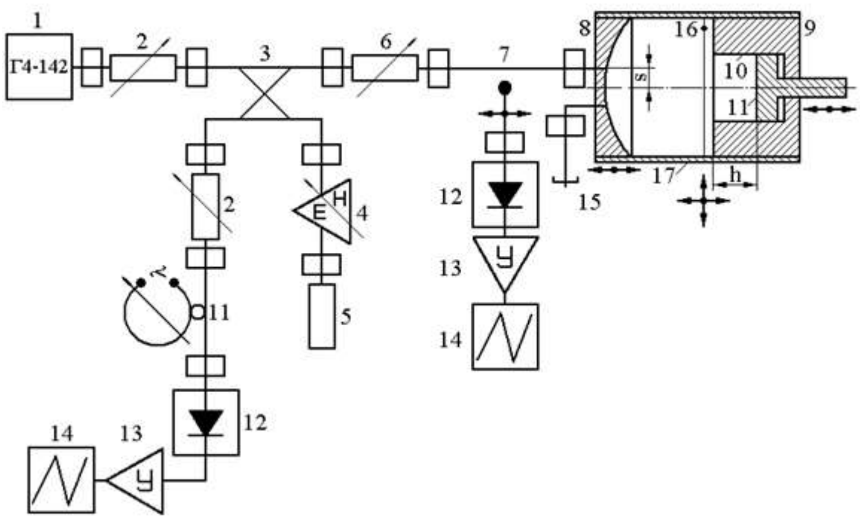

Fig. 1. A block diagram of an experimental setup for investigating the excitation of various oscillations in an OR effectiveness using a slot coupling element

The resonator is formed by a flat mirror 9 with an aperture of 38 mm and a spherical focusing mirror 8 with the same aperture and radius of curvature = 39 mm. In the center of the flat mirror there is a segment of an oversize circular waveguide 10 with a piston 11 in length. The coupling elements are smooth transitions from a reduced section of 3.6´ 0.16 mm to the main section of the waveguide of 3.6 1 1.8 mm (connection gap) located on a spherical mirror at a distance of = 5.5 mm from the axis of the OR.

All measurements were carried out in the four-millimeter wavelength range. A high-frequency signal generator Г4-142 is used as an excitation generator. To expand the dynamic range, the microwave signal is modulated in amplitude by a sinusoidal voltage with a frequency of 1 kHz. The generator is decoupled from the OR using an installation attenuator 2. An additional receiving path is provided for visual adjustment of the system to resonance (the signal reflected from the OR is minimal). The structure of this path includes: a directional coupler 3, an installation attenuator 2, a resonant wave meter 11 for controlling the generator frequency, a crystal detector 12, a resonant amplifier 13 tuned to the frequency of the modulating voltage, and an oscilloscope 14. At the shoulder of the directional coupler containing a matched load 5, is located the coordinator 4, which allows to compensate for the possible signals reflected from the waveguide connections, which can distort the tuning accuracy to resonance. The signal proportional to the amplitude of the standing voltage wave in the waveguide is recorded by a measuring line 7 of type P1-40 and enters the receiving path consisting of a crystal detector 12, a resonant amplifier 13 and an oscilloscope 14. As we consider the OR included in the reflection circuit, then The output of the second coupling element includes a short-circuit piston 15. To identify the types of oscillations excited in the resonator, a test body 16 is used, attached to a nylon filament near a flat mirror. The RC (reflection coefficient) of the investigated OR is calculated by the formula $RC=10^{A/20}$. Here A is the difference between the maximum and minimum attenuation values of the polarization attenuator 6 in dB.

To find the reflection coefficient from the resonator, we use the formulas: $G=(RC-1)/(RC+1)$ при $G>0$ и $G=(1-RCt)/(1+RC)$ при $G<0$. The system is tuned to resonance by moving the spherical mirror of the resonator. The distance between the reflectors is determined using a measuring projection device MPD – 23 with an accuracy of 1 μm.

For finding η it is necessary to measure the reflection coefficients (RC) from the OR and the reference OR (EOR) – a resonator with the same field distribution as in the open, but in which there is no energy emission into the surrounding space. For this, a screening cylinder 17 is put on the OR. Such a comparison of two resonators is justified, since the ohmic losses in the walls of the screening cylinder for the considered oscillations TEM_{01q} and TM_{01q} can be neglected. This is due to the fact that both oscillations have no longitudinal component of the magnetic field (H_2=0). Therefore, when we put a shielding cylinder on the OR, we actually eliminate the connection between the OR and free space. In addition, it was shown in [2] that the oscillations excited in the EOR have the parameters of the resonant beam, which coincide with the parameters of the corresponding oscillation in the OR. Based on all the above, we can consider the EOR as a closed resonator corresponding to the OR.

Using the measuring line P1-40, it was shown that the displacements of the minimum of the standing voltage wave in the line when tuned to resonance OR and EOR, excited by the same coupling element, coincide with the accuracy of the measurement error. This confirms the correctness of the conclusion about the equality of the resonant frequencies of the PR and EOR. The shift of the minimum of the standing wave voltage in the waveguide for the resonator of the considered geometry was Δl=-0.033 mm.

In fig. 2 shows the dependences G_{OR} (curve 1) and G_{EOR} (curve 2) on the change in the relative distance *L/R* between the hemispherical OR and EOR mirrors, in which the TEM_{01q} oscillation is excited using a gap coupling element. During these measurements, the piston 11 is flush with the flat mirror 10 of the resonator (see Fig. 1). As can be seen from the figure, in almost the entire resonance tuning range, the coupling with the load is strong ($G<0$). The change in and at *L/R*=0,505 (semi-focal resonator geometry) is due to the fact that in this case the TEM_{019} oscillation interacts with another oscillation of the resonant system. It also shows the dependence of the excitation efficiency coefficient η on the relative distance between the mirrors *L/R* (curve 3).

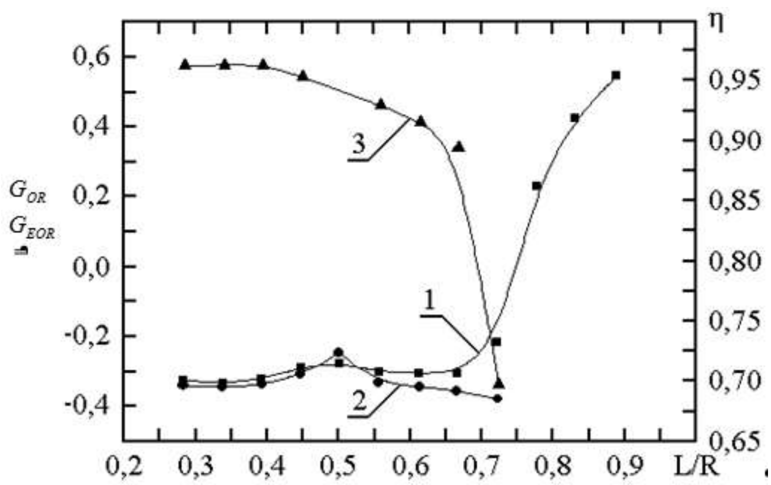

Fig. 2. Dependencies of reflection coefficients G_{OR}, G_{EOR} and excitation efficiency η on the distance between the mirrors *L/R* for TEM_{01q} oscillation, excited in the OR by a gap coupling element

As can be seen, as the distance between the resonator mirrors decreases, the diffraction losses decrease and η increase, reaching values of 0.96 at *L/R* < 0,4; which is in good agreement with the results obtained in [1, 3]. In the region of large diffraction losses ((> 0,7)), the excitation efficiency of TEM_{01q} oscillations in a hemispherical OR does not exceed 0.78. In this case, it is rather difficult to experimentally determine the efficiency of the excitation of oscillations in a resonant system. This is due to the fact that when a shielding cylinder is worn on the OR in the region of high diffraction losses in the resonant volume, others will be excited along with the oscillation under study. As a result, this will lead to a distortion of the measurement results. The maximum Q-factor for an open resonant system corresponds to the case of equality of diffraction and ohmic losses. As can be seen from the figure, the maximum loaded Q-factor in the OR of hemispherical geometry has the TEM_{0112} oscillation (*L/R*=0,669, Q_H=2820). In this case, however, the η value does not reach the maximum value, and is only 0.9.

As a next step, we analyze the behavior of the Q-factors both in a hemispherical OR and in a resonator with a segment of an oversized circular waveguide. We will consider the loaded Q-factor Q_L, the Q-factor of the coupling of the resonant system with the supplying waveguide path Q_{SW} and its own Q-factor Q_0. Fig. 3 shows the behavior of Q_L (curve 1), Q_{SW} (curve 2) and Q_0 (curve 3) when the distance between the mirrors of a hemispherical OR changes, in which the non-axially symmetric type of TEM_{01q} oscillations is excited.

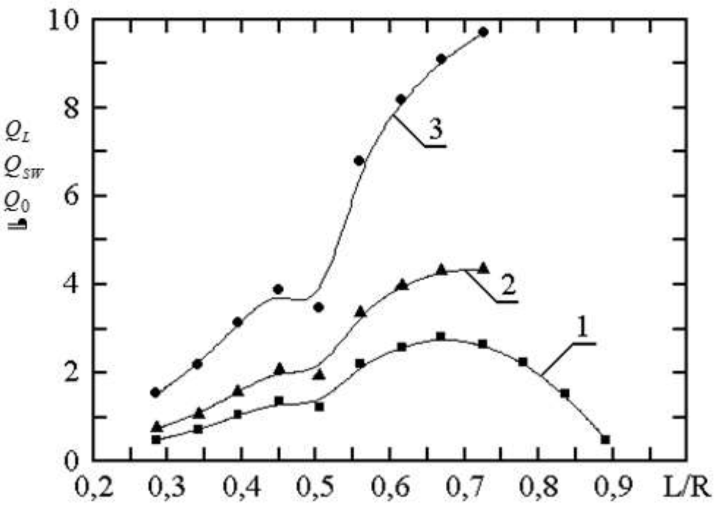

Fig. 3. Dependences of *Q*-factors Q_L, Q_{SW} and Q_0 on the distance *L*/*R* between the mirrors for oscillation of TEM_{01q}, excited in a hemispherical OR with a slot coupling element

The loaded Q-factor was measured by the half-width of the resonance curve [5]. Q-factors Q_{SW} and Q_0 are calculated from expressions, because for each value g we know Q_L, G_{OR} and G_{EOR}. The figure shows that the maximum quality factor G_L=2820 has the TEM_{0112} oscillation at L/R=0.669. The decrease in all types of Q-factors at *L/R*=0.505 is associated with the interaction of the studied vibration with one of the oscillations of the resonance system (semi-confocal geometry of the resonant system). At *L/R*<0.7, the coupling of the resonator with the waveguide path is strong (see Fig. 2), therefore, in this case, Q_L should be mainly determined by the quality of coupling. This we clearly see from the figure. Determine Q_{SW} and Q_0 when *L/R*>0.725 is a difficult task. This is due to the difficulties of measurement , since when a shielding cylinder is put on on the OR at large distances between the mirrors, additional oscillations, as a rule, are excited in the resonant volume, interacting with the object under study. And this, in turn, can lead to an incorrect measurement result.

For the resonance system OR with a segment of an oversize circular waveguide, the maximum value Q_L=2170 at L/R= 0.559 (type of vibration TM_{0116}). As mentioned above, the decrease in loaded Q-factor for such a resonant system is associated with additional ohmic losses. In this case, the general behavior of all types of Q-factors for the OR with a segment of an oversize circular waveguide is identical to a hemispherical OR. The reason why we could not determine and for > 0.559 is the same as in the previous case.

Conclusions. To measure small shifts of the resonant frequency when a measured object is placed in the OR volume, it is necessary to increase. Thanks to this, we have significantly increased the sensitivity of the measurement setup. Determination of parameters of acoustic oscillations for the impact on micro-objects of animals before their cryopreservation is necessary using the developed installation based on open resonators formed by spherical and flat mirrors, with the parameter: aperture of mirrors 60mm; spherical mirror curvature radius 110mm; the ratio L/R = 0,579; the distance from the axis of the mirrors to the gaps is 9.4 mm; resonant frequency 74.278 GHz; loaded Q-factor of the resonators Q = 4120.

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Н. П. Кунденко, О. Ю. Єгорова, И. М. Шинкаренко, И. И. Бородай, А. Н. Кунденко. **Измерения диэлектрической проницаемости биологических веществ.**

Для измерения электрофизических параметров веществ наибольшее распространение получили резонансные методы в силу высокой точности получаемых результатов. Основная идея всех резонансных методов состоит в наблюдении резонансных кривых колебательного контура, в который помещен образец исследуемого вещества. Проведенный анализ работ показал, что точность измерений диэлектрической проницаемости зависит от стабильности частоты генератора и добротности измерительного резонатора. Аппаратура, предназначенная для измерения изменений диэлектрических параметров жидкости, должна обеспечивать не только необходимый уровень подводимой мощности и частоты сигнала, но и удовлетворять высоким требованиям к стабильности частоты, степени подавления дискретных составляющих в спектре выходного сигнала, габаритам, надежности, экономичности и срока службы.

Ключевые слова*: диэлектрическая проницаемость, резонатор, колебания, частота, возбуждение, волновод, измерения.*

М. П. Кунденко, О. Ю. Єгорова, І. М. Шинкаренко, І. І. Бородай, О. М. Кунденко. **Вимірювання діелектричної проникності біологічних речовин.**

Для виміру електрофізичних параметрів речовин найбільше поширення отримали резонансні методи у зв'язку з високою точністю отримуваних результатів. Основна ідея усіх резонансних методів полягає в спостереженні резонансних кривих коливального контура, в який поміщено зразок досліджуваної речовини. Проведений аналіз робіт показав, що точність вимірів діелектричної проникності залежить від стабільності частоти генератора і добротності вимірювального резонатора. Апаратура, яка призначена для виміру змін діелектричних параметрів рідини, повинна забезпечувати не лише необхідний рівень потужності, що підводиться, і частоти сигналу, але і задовольняти високим вимогам щодо стабільності частоти, мірі пригнічення дискретних складових у спектрі вихідного сигналу, габаритам, надійності, економічності і терміну служби.

Ключові слова*: діелектрична проникність, резонатор, коливання, частота, збудження, хвилевід, виміри.*